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# Sensor systems to Detect Combustion Summary of Instrumentation

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October 15, 2010

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# **Sensor systems to Detect Combustion**

## **Summary of Instrumentation**

Ray Mariella Jr.  
Oct 2010

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**I. Analytical Capability: Desired analytical characteristics are listed below**

Target Analyte Detection Desired	Range (ppm)	Accuracy (%)	Precision (%)	Resolution	Specificity in complex mixture
CO	0 - 500	6-12%	10 - 20	1	high
HCN	0.4 - 300	20%		0.1	high
Desirable Analytes					
O <sub>2</sub> (%)	14-32			0.1%	
CO <sub>2</sub>	0.05– 3.0			0.1%	
HX	0.4-30			0.1 ppm	

**II. Frequent Comments – Perform “Bake-offs” = Field Trials:**

The majority of the panel felt that testing multiple instruments and types of instruments with complex mixtures would be an important reality check for confounding factors, sensitivity, and specificity.

Ray’s note: NASA should make known the nature of the test mixtures of interest to them. [Include aerosolized lunar regolith for some applications? Ability of a combustion system to distinguish between combustion-generated smoke and suspended lunar regolith?]

Note: It is easy to envision scenarios in which unknown and/or unexpected vapors could be produced, not just due to equipment overheating, but also due to metabolic and by-product gases from microbes and even from the crew. It may be challenging to create relevant challenge mixtures for testing instruments. Nonetheless, simply asking the manufacturers if their instruments can detect low concentrations of pure target gases is necessary but not sufficient to establish the value and reliability of combustion-sensing instruments.

**III. Recommendation – Data Fusion:**

Whether it be with neural nets or other algorithms, [the panel did not seem to have a strong recommendation on the specifics of the algorithm(s)] tie together more than one type of sensor into a combustion sensor system.

A few speakers and most of the panel acknowledged that highly-reactive gases such as HCl and HF have challenges of sample collection and sample transport – chemisorption and physisorption to any collection tubing could easily lead to false negatives. The transduction element, *per se*, does not tell the entire story of performance with any particular instrument.

As of Sept 2010, the VIS/IR technologies appeared to have much better specificity [much lower probability of confounding detection that could lead to false (+) or false (-)], but technical readiness was not high enough for short-term inclusion on an upcoming flight. Solid state detectors suffered from drift, lack of internal calibration, and serious lack of specificity, including pathological cases in which one gas would counteract the detection of CO.

## IV. Technologies

### 1. Visible and Infrared Spectroscopy, including Raman Spectroscopy

Assuming that such spectroscopy-based gas monitors use solid-state sources and detectors, power consumption of 1 W or less per target gas can be anticipated.

All molecules, including N<sub>2</sub>, O<sub>2</sub>, CO, H<sub>2</sub>O, and CO<sub>2</sub>, possess identifying excited electronic states at higher energies than their lowest [“ground”] electronic states, and these excited states can be accessed by the absorption of electromagnetic radiation, usually falling in the ultraviolet wavelengths. Strongly-allowed transitions occur between ground and electronic states that maintain the overall electron spin, such as singlet to singlet [no unpaired electrons] and triplet to triplet [two unpaired electrons]. Accessing the strongly-allowed electronic transitions for all five of the gases just listed requires the use of ultraviolet light that is not eye safe [and may even generate ozone]. Weakly-allowed transitions between a ground-state and states with different overall electron spins can occur. The most famous of these is the transition between ground state O<sub>2</sub>, which is a triplet, and its lowest excited state, which is a singlet. Although absorption of the corresponding 765-nm light for this transition is relatively weak, it can be observed, nonetheless, for the O<sub>2</sub> in breathable air and is the basis for numerous oxygen monitors.

For many molecules of interest [HCN, HCl, NH<sub>3</sub>, CO, CO<sub>2</sub>, H<sub>2</sub>O, chlorofluorocarbons, gases on the SMAC list], characteristic “fingerprint” vibrational spectra are observed via absorption of light at infrared [IR] wavelengths.

Researchers have used such absorption for stand-off characterization of combustion processes<sup>1-5</sup>.

1 ppm detection limits are possible with strong transitions of diatomic molecules with permanent dipole moments and transitions that are free from confounding absorptions, with the caveat for HF, HCl that delivering the sample to the spectrometer cannot have surfaces that “getter” these reactive gases.

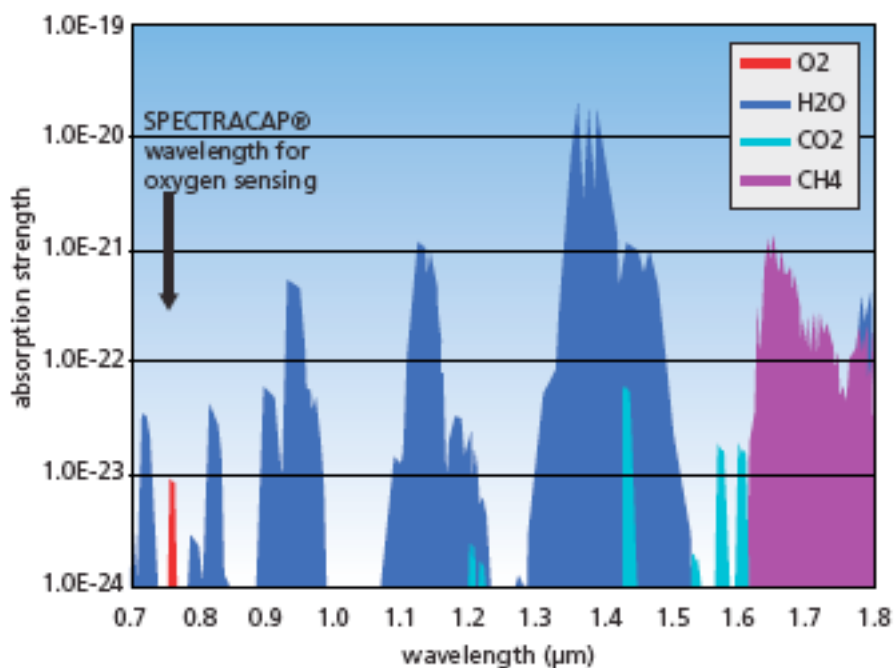
Physical Sciences, Inc: limits are in ppm-m, or on a per-meter probing  
Paper No. 162

TABLE I  
SOME GASES MEASURED BY NEAR-INFRARED TDLAS

Gas	Detection Limit (ppm-m)	Gas	Detection Limit (ppm-m)
HF	0.2	HCN	0.2
H <sub>2</sub> S	20.0	CO	40.0
NH <sub>3</sub>	5.0	CO <sub>2</sub>	1.0
H <sub>2</sub> O	1.0	NO	30.0
CH <sub>4</sub>	1.0	NO <sub>2</sub>	0.2
HCl	0.2	O <sub>2</sub>	50.0
H <sub>2</sub> CO	5.0	C <sub>2</sub> H <sub>2</sub>	0.2

basis

Numerous embodiments of detection systems based on tunable diode lasers – transduction mechanisms can be direct optical detections or could be photoacoustic [transduction based upon detecting a pressure pulse from the thermal energy deposited as a result of the absorption of the E-M radiation]. Both direct absorption and photoacoustic techniques use either amplitude modulation or frequency modulation with synchronous detection of the modulation to enhance the signal-to-noise ratio.



Note that the triplet-singlet transition of O<sub>2</sub> does not overlap other common gases.

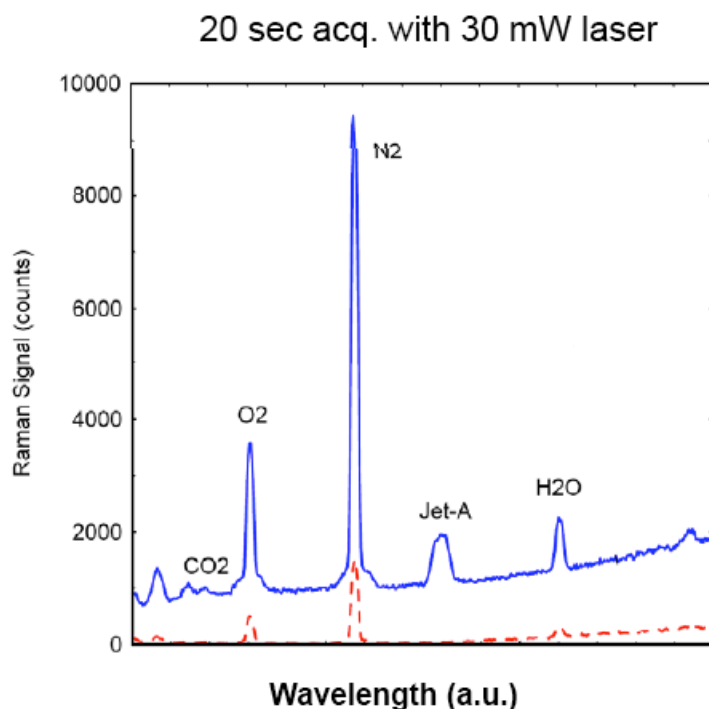
Bloodhound™ TDL instrument: Molecular species measurements of O<sub>2</sub>, CH<sub>4</sub>, CO, CO<sub>2</sub>, NH<sub>3</sub>, H<sub>2</sub>O, and many other small molecules.

Using tunable diode lasers, both overtone absorption as well as absorption at the fundamental frequency of a vibration-rotation transition are possible, the latter using mid-IR sources [emerging and/or custom devices, in many cases]

N<sub>2</sub> and O<sub>2</sub> do not possess polar bonds and do not exhibit vibrational spectra in the infrared light region. However, as present within typical, breathable air, N<sub>2</sub> and O<sub>2</sub> can be monitored using *Raman spectroscopy*, in which light [usually visible light] almost always from a laser, is inelastically scattered off of the molecule with the characteristic energy change corresponding to the vibrational frequencies of the molecule. Although the cross sections for such Raman scattering of blue light are very small [ $\approx 10^{-31}$  cm<sup>2</sup>/molecule/steradian], Raman scattering by N<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub>O, and CO<sub>2</sub> is routinely observed in breathable air, nonetheless.

**Note: No approach using Raman spectroscopy was presented**

Both traditional Raman techniques<sup>6</sup> as well as photoacoustic Raman techniques have been published – possibility to meet size, power, and ruggedness requirements are unknown. Nonetheless, I support including a Raman-based instrument for general gas analysis, including N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>O



Raman spectra showing N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, and H<sub>2</sub>O taken using a single-pass, fiber-optic system by Q-V Nguyen, of NASA GRC<sup>7</sup>

N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub> – demonstrated since 1968 with Raman<sup>6</sup>

Intra-cavity configurations enhance Raman sensitivity<sup>8-10</sup>

Photoacoustic Raman spectroscopy [PARS] demonstrated<sup>8,9,11,12</sup>

Trace gas application: The method has been applied to the analysis of mixtures of CH<sub>4</sub> in N<sub>2</sub>, CO<sub>2</sub> in N<sub>2</sub>, and N<sub>2</sub>O in N<sub>2</sub> at concentrations near 1 ppm.<sup>8</sup>

Table I. Sensitivity Limits for PARS Trace Analysis

Sample	Monitored transition	Buffer gas	$E_s$ (mJ)	$E_p$ (mJ)	Concentration (ppm)	Observed SNR	SNR = 1 limit (ppm)	Laser <sup>a</sup> system
CH <sub>4</sub>	$\nu_1 \leftarrow 0$	N <sub>2</sub>	14.5	50	2	2	1	QR
CO <sub>2</sub>	$\nu_1 \leftarrow 0$	N <sub>2</sub>	18	20	6.3	2.5	2.5	QR
CO <sub>2</sub>	$\nu_1 \leftarrow 0$	N <sub>2</sub>	3.0	9	250	2	125	M
N <sub>2</sub> O	$\nu_1 \leftarrow 0$	N <sub>2</sub>	27	15	100	5	20	QR
N <sub>2</sub> O	$\nu_1 \leftarrow 0$	N <sub>2</sub>	≤1.5	10	1400	2	700	M
C <sub>2</sub> H <sub>4</sub>	$\nu_3 \leftarrow 0$	N <sub>2</sub>	2.4	10	350	2	175(4) <sup>b</sup>	M
C <sub>2</sub> H <sub>3</sub> Cl	$\nu_4 \leftarrow 0$	N <sub>2</sub>	3.8	11	360	1	360(9) <sup>b</sup>	M
O <sub>2</sub>	$1 \leftarrow 0 = \nu$	C <sub>2</sub> H <sub>4</sub>	3.5	9.5	2000	5	400(10) <sup>b</sup>	M

<sup>a</sup> QR = high-power dye laser (Quanta-Ray); M = low-power dye laser (Molelectron).

<sup>b</sup> The values in parentheses are the anticipated sensitivity limits with the QR system, assuming a typical sensitivity improvement factor of 40x at the higher laser energies.

With excitation at 488 nm, the Raman cross section<sup>13</sup> for CO is 8x smaller than that of CH<sub>4</sub>, which should still provide 10's of ppm sensitivity for CO detection with little risk of interference.

Somewhat tilting at windmills, here, but Privalov estimated 10<sup>13</sup>/cm<sup>3</sup> [order of 1 ppm] detection of HF at standoff distance of 1 meter. HCl would also have a larger Raman scattering cross section<sup>14</sup> than CO [lower limit of detection].

Low TRL:

**Cavity-ringdown spectroscopy**<sup>15</sup> is not high TRL, yet.

Because cavity-ringdown spectroscopy ["CRS"] requires a very high-Q optical cavity [extremely high-reflectance mirrors and very low losses, overall, aside from the absorption of the gaseous molecules of interest], any mechanism that degrades the Q also concomitantly degrades the performance of the CRS instrument. This can include "errant" aerosol particles and films that gradually build up on the surfaces of the optics, etc. Other issues to be addressed would be evaluation of possible cross-signals from multiple species and the tradeoff between narrowing the bandwidth of the excitation light source to reduce or eliminate such cross-signals and the accompanying tradeoffs of signal strength and rapidity with which a mixture of many gases at widely-differing concentrations can be monitored.

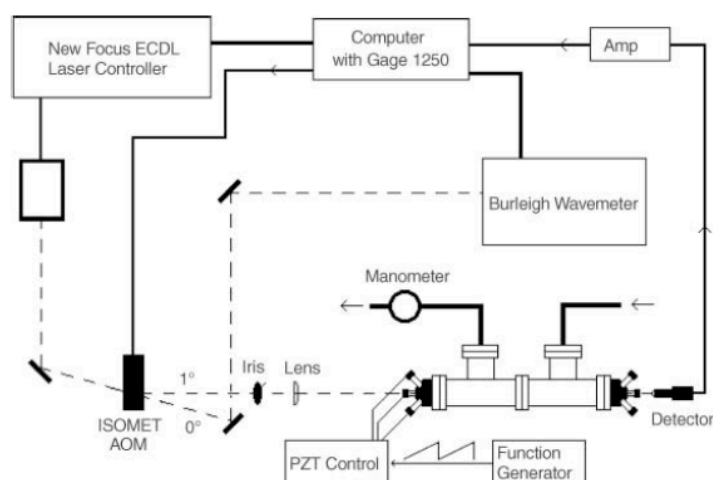


FIGURE 1 Schematic layout of the experimental set-up

A continuous-wave (cw), external-cavity tunable diode laser centered at  $1.55\ \mu\text{m}$  is used to pump an optical cavity absorption cell in cw-cavity ringdown spectroscopy (cw-CRDS). Preliminary results are presented that demonstrate the sensitivity, selectivity and reproducibility of this method. Detection limits of 2.0 ppm for CO, 2.5 ppm for CO<sub>2</sub>, 1.8 ppm for H<sub>2</sub>O, 19.4 ppb for NH<sub>3</sub>, 7.9 ppb for HCN and 4.0 ppb for C<sub>2</sub>H<sub>2</sub> are calculated. [From the abstract of Awtry&Miller<sup>15</sup>]

## 2. Mass Spectrometry and IMS

**Note: no Mass Spec nor IMS was presented to the Panel.** This is not equivalent to saying that none is a viable technology – very small ion-trap-based instruments have been built<sup>17-19</sup>{A. Chutjian, 200 #169}.

Facundo F. will provide a more-complete overview of Mass Spectroscopy and Ion-Mobility Spectroscopy.

Ray's view: the basic problem with MS is that simple instruments cannot distinguish between CO and N<sub>2</sub>. IMS, in general, does not provide identification of observed peaks, but can be very useful with known sample streams and can work at or near atmospheric pressure.

Mass spectroscopy provides the mass/charge ratio of detected ions. Most commercial mass spectrometers view only positive ions, so that operators must include in their interpretation that some ions decompose rapidly when forming positive ions [e.g., alcohols] and the parent peak may not be dominant, such as can occur under some conditions for NH<sub>3</sub><sup>20,21</sup> nor even be easily visible<sup>22</sup>. Also negative ions that might provide valuable insights are not, typically, available [exceptions: ions detected from bombardment of solids using dual-polarity detection<sup>20,21</sup> and aerosol flow cytometer/mass spec<sup>23,24</sup>]. Both positive and negative ions are available with an IMS<sup>25-27</sup>. One failure mode is that the ionizer on a MS can become degraded or burn out, particularly if the MS sees high gas loads. Also, if insulating deposits grow on surfaces over time, then they can become charged, changing and degrading the performance of the MS or IMS. [This is especially true of a miniaturized or microfabricated system that

is exposed to high loads of unfiltered air, because a smaller instrument tends to have a larger surface-to-volume ratio – it is easier for vital surfaces to become covered in an undesirable film, although progress is certainly being made<sup>28</sup>.]

In general, even “low-power” mass spectrometers require 10’s of watts of power to operate and require extensive supporting electronics to observe all the masses on a scan and to assign an observed fragmentation pattern back to one or more parent compounds with varying concentrations. By contrast, there are numerous, battery-powered, handheld IMS instruments that can detect a variety of vapors but that offer far less identification powers than are available with a MS.

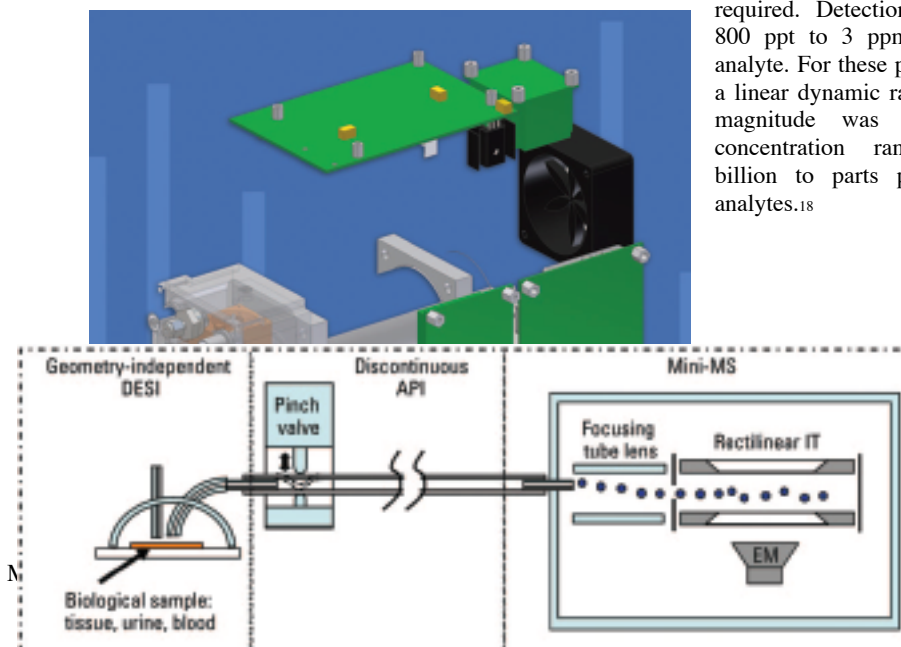
Note: The specifications for Combustion Instrumentation seem to have precluded GC-MS instruments, but Ray recommends including one on board as a general-purpose analytical instrument.

### **Mass spectrometers [“MS”]**

Mass spectrometers, *which generally need to operate under vacuum [often under high vacuum]*, produce and disperse/separate beams of atomic and molecular ions according to their differing mass-to-charge ratios, and are general-purpose analytical devices that are particularly useful for the identification of one or a few gaseous species. With training, the operator can increase the identification power of a MS by analyzing the fragmentation pattern<sup>29</sup>, resulting from the ionization of the parent molecule that is observed from a sample. R. Cooks and co-workers have published numerous articles on small, portable MS’s<sup>18,30-32</sup>, including some designs that operate at ambient pressure<sup>17,33,34</sup> and have biomedical applications.<sup>34</sup>

Possible configurations: time-of-flight<sup>28</sup>, quadrupole<sup>35</sup>, and ion-trap designs<sup>19</sup>. Please see the excellent review by Palmer and Limero<sup>36</sup>. The advantage of mass spectrometers that are based on ion traps is their relatively small size and weight, which makes them particularly appropriate for NASA applications.

For toxic gases, such as phosgene, ethylene oxide, sulfur dioxide, acrylonitrile, cyanogen chloride, hydrogen cyanide, acrolein, formaldehyde, and ethyl parathion, a 1-minute preconcentration time is required. Detection limits range from 800 ppt to 3 ppm, depending on the analyte. For these particular compounds, a linear dynamic range of 1-2 orders of magnitude was obtained over the concentration range (sub-parts per billion to parts per million) for all analytes.<sup>18</sup>



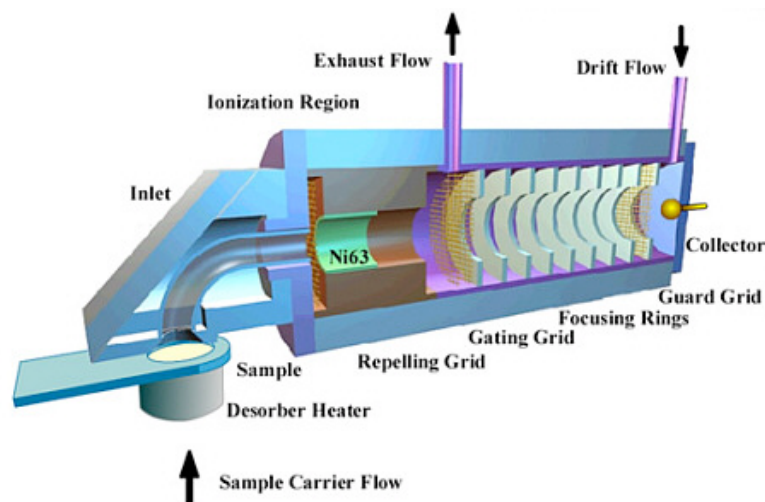
### **Ion Mobility spectrometers [“IMS”]**

An IMS, which can be miniaturized/handheld, ionizes gaseous molecules and analyzes their various drift speeds in an applied electric field. The analysis and characterization via IMS are based on differing ionic mobilities through a background or carrier gas rather than simply their differing  $m/z$ . *An IMS typically operates at or near atmospheric pressure.* [IMS units can analyze air, vapor, soil, and water samples; for analysis of volatile components of liquid or solid materials, the volatile components must be introduced to the instrument in the gas phase, requiring sample preparation.]

R&D teams working<sup>26</sup> with or independent of NASA have created portable IMS and/or GC-IMS systems: amongst others – Gary Eiceman and Erkinjon Nazarov<sup>26,37-44</sup>. [Dr. Nazarov invented a new kind of differential ion-mobility spectrometer<sup>37-41,43-49</sup> with reduced volume and weight, now incorporated in the Sionex microAnalyzer™. See, e.g., Thomas Limero, et al.<sup>50-53</sup>] Such systems can be very small and lightweight and the Sionex instrument, which is already under test by NASA personnel, appears well-suited for space applications. Numerous hand-held IMS instruments incorporate drift tubes manufactured by Graesby<sup>54</sup>. See Appendix A2. Including the Chemical Agent Monitor [CAM] that is used by the military and police.

Also, see work by Dr. Pete Snyder<sup>55</sup>, including detection and characterization of bioaerosols<sup>56-58</sup>.

Graseby Ionics, Ltd. has a self-contained IMS that weighs about 2 kg.



Smiths Detection

### **Ion Mobility Spectrometry (IMS)**

Mobility ( $K$ ) is determined from the drift velocity ( $vd$ ) attained by ions in a weak electric field ( $E$ ) in the drift tube, according to the equation,  $vd = K \times E$ . The distribution of these signals forms an ion spectrum, with an ion mobility band corresponding to each of the unique ionic species. The spectrum is a fingerprint of the parent compound



[Photo of ICAM]The Improved Chemical Agent Monitor is an improvement over the currently fielded CAM. The modular design is less expensive to repair, requires less maintenance, and eliminates depot level repair now required for the CAM. The ICAM also starts up faster after prolonged storage and is more reliable.

FemtoScan: EVM II instrument uses Graesby drift tubes,



### 3. Solid-State Sensors

Solid-state sensors can be very compact, low-mass, and low-power, but they are susceptible to deposition of films from continuous exposure to the atmosphere as well as gradual oxidation or other chemical reactions or physical changes of the transduction components that could degrade its performance. Calibration would always be an issue. The influence of interfering gases such as O<sub>2</sub>, H<sub>2</sub>O, CO, NO, NO<sub>2</sub>, CH<sub>4</sub> and SO<sub>2</sub> on a CO<sub>2</sub> sensor has been reported in literature, such as O<sub>2</sub> for a CO<sub>2</sub> sensor<sup>59</sup>. Degradation due to exposure to ionizing radiation may also be an issue.

**Note: no “electronic nose” or similar technology was presented.** In the past, these eNose architectures have included numerous, less-specific transduction elements, but there is no reason that such an instrument could not include both “specific” solid-state or electrochemical transducers along with the less-specific ones. Clearly, this would require some effort to create. If such an electronic nose were included as part of a mission, for non-combustion-sensing applications, it would still be valuable to include it in testing challenge mixtures in order to improve the signature capability of any data-fusion algorithms.

From Figaro, Inc.:

#### Electrochemical



##### *Solid state electrolyte type*

Figaro was the first company to successfully commercialize solid state electrolyte CO<sub>2</sub> sensors by using a Figaro patented technology. This CO<sub>2</sub> sensor has compact size, low power consumption, and has lower cost and longer life than conventional Infra-red sensor technology.



##### *Liquid electrolyte type*

This type of sensor shows good accuracy, linear response, and exhibit excellent selectivity to its target gas. Since liquid electrolyte sensors can be operated without heat, they can be used in the development of battery operated sensing devices. Unlike traditional electrochemical sensors, Figaro's sensors are designed for environmental safety, using weak alkaline electrolyte.



##### **Catalytic**

The catalytic type gas sensor is a long established technology. The principle is based on combustion of the target gas on a heated catalyst, producing heat which is measured in order to determine the presence of gas. Figaro's 35+ years of experience in catalyst material technology and its advanced micro fabrication technology enable production of the most advanced compact pellistor sensors whose durability, stability, quick response, and linear output make them ideal for detecting many combustible gases.

Active surfaces: Pt [for hydrocarbons] or Pd [for CO & H<sub>2</sub>] added to SnO<sub>2</sub>, ZnO<sub>2</sub>, ZrO<sub>2</sub> etc.

Also, the long-awaited ChemFET remains a technology of tomorrow<sup>60</sup>.

Here is a study of interferences for a carbonate-based CO<sub>2</sub> sensor<sup>61</sup>, showing that SO<sub>2</sub> causes irreversible changes in performance:

**Influence of interfering gases on the sensor signal in the presence of CO<sub>2</sub>**

Interfering gas	Partial pressure/ conc.	Changes of EMF		
		Type A open ref.	Type B and C solid ref.	Problem
O <sub>2</sub> influ- ence	>0.1 bar	No	No	–
	<0.1 bar	No	Nernst (38 mV/dec.)	RE (solid)
H <sub>2</sub> O	0.012 bar (50% r.h.)	+10 mV reversible	No	RE (open)
CO	30 ppm	No	No	–
CH <sub>4</sub>	200 ppm	No	No	–
NO <sub>2</sub>	100 ppm	Reversible	No	RE (open)
SO <sub>2</sub>	≥500 ppb	Irrevers.	Irrevers.	WE
	50–500 ppb	Irrevers.	No	RE (open)
	≤50 ppb	No	No	

and adding chemical filters can reduce interference by NO and SO<sub>2</sub> on CO<sub>2</sub> sensor<sup>62</sup>

Water vapor shows interferences for solid-state CO or NH<sub>3</sub> sensors{Raj, 2006 #174  
Reducing gases interfere with CO sensor [formaldehyde, methane]}

**a. Electrochemical Sensors**

Solid or membrane electrolytes [These can be very compact and draw little power ] or fuel-cell arrangements - used in some hand-held CO sensors for breathable air{Bermudez, 2003 #145}, exhaled alcohol and exhaled NO sensors<sup>63,64</sup>. Cross reactivity/confounding gases may be a source of degraded accuracy/reliability

**b. Surface-sensitive Sensors**

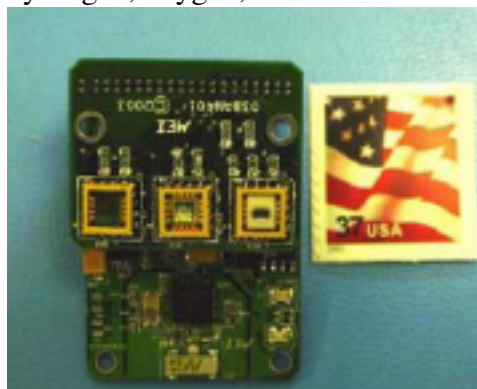
Dr. Meyyappan and co-workers, using principal component analysis, have created nanotube-based sensors<sup>65,66</sup> and some are currently incorporated into the JPL electronic nose and serving on the ISS.

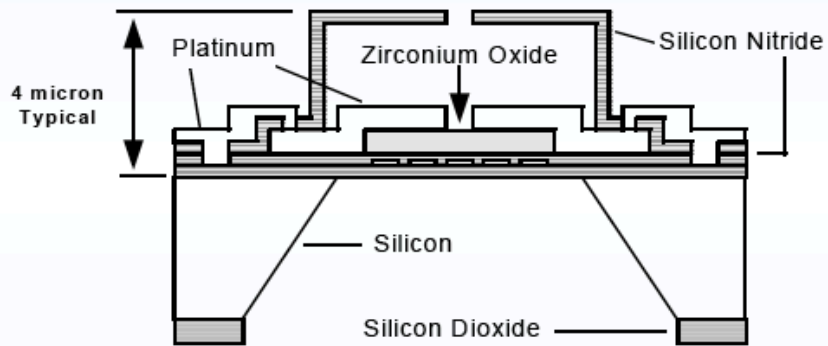
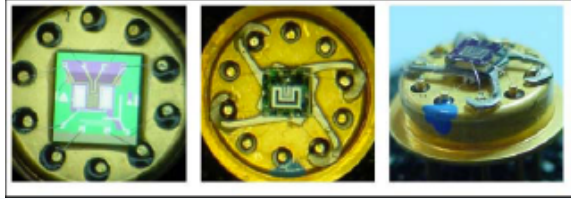
**Combined in assembled instruments that detect up to 5 different vapors**

**Makel Engineering** already working with NASA personnel  
 Makel Engineering – hypergolic fuel detection “Lick and Stick” technology

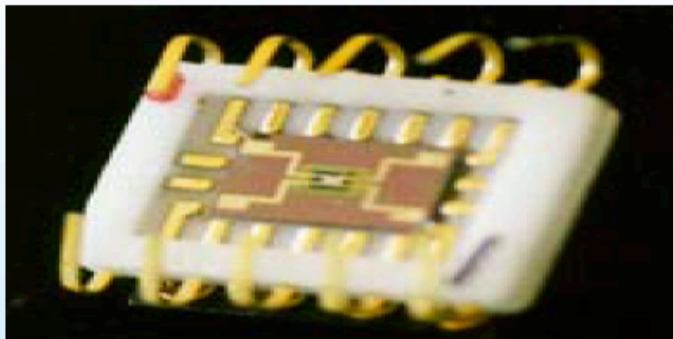


hydrogen, oxygen, and methane.

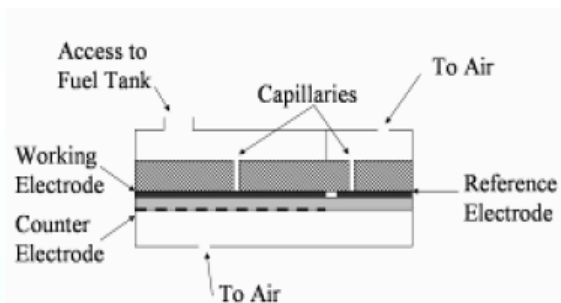




Not to scale:



**ZrO<sub>2</sub> Oxygen Sensor**



## NAFION O2 Sensor Structure Glenn Research Center

DIMENSIONS: ( Approx. 5.63 CM X 3.13 CM X 3.44 CM )

**POWER: < 400 mW**

**MASS: < 300 g PER UNIT**

DATA RATE: 50 SAMPLES/SEC

HARDWIRED FOR POWER AND DATA

H2; RANGE ACCURACY

-50 PPM TO 250 PPM  $\pm 25$  PPM

250 PPM TO 40,000 PPM  $\pm 10\%$  OF READING

**Combined solid-state and IR-based Instruments:** H<sub>2</sub>S, CO, O<sub>2</sub>, SO<sub>2</sub>, PH<sub>3</sub>, NH<sub>3</sub>, NO<sub>2</sub>, HCN, Cl<sub>2</sub>, ClO<sub>2</sub>, O<sub>3</sub>, and combustibles as well as CO<sub>2</sub> via IR absorption

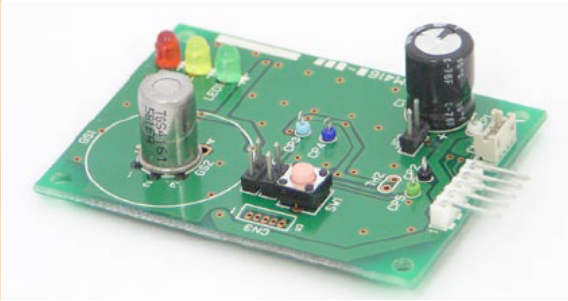
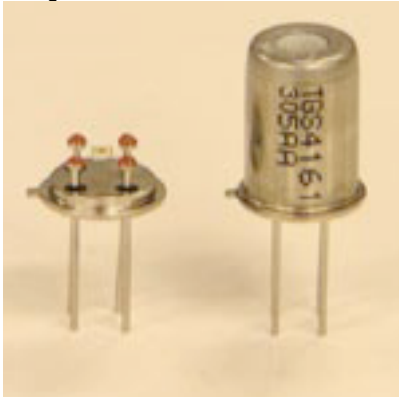


Gas	Range (ppm)	Default Resolution (ppm)	High Resolution (ppm)
<b>H2S</b>	0-500	1	0.1
<b>CO</b>	0-999	1	N/A
<b>TwinTox(H2S)</b>	0-500	1	0.1
<b>TwinTox(CO)</b>	0-500	1	N/A
<b>O2</b>	0-30.0%	0.10%	N/A
<b>SO2</b>	0-150	1	0.1
<b>PH3</b>	0-5.0	1	0.1
<b>NH3</b>	0-100	1	0.1
<b>NO2</b>	0-99.9	1	0.1
<b>HCN</b>	0-30.0	1	0.1
<b>Cl2</b>	0-50.0	1	0.1
<b>ClO2</b>	0-1.0	0.1	0.01
<b>O3</b>	0-1.0	0.1	0.01
<b>PID(VOCs)</b>	0-1000	1	N/A
	0-50,000		
IR(CO2)	0-5.0% v/v	150 0.01%	N/A
Combustible gases	0-100% LEL 0-5.0% v/v	1% or 0.1%	N/A

**Figaro [Japan]**

Model	Target gas	Typical detection range	Ps	Description
TGS2620	Alcohol, Solvent vapors	50 - 5,000ppm	210mW	Compact size, For breath alcohol testers and solvent detectors
TGS826	Ammonia	30 - 300ppm	833mW	Ceramic base resistant to severe environments
TGS2444	Ammonia	10 - 100ppm	56mW	High selectivity to ammonia
CDM4161	Carbon dioxide Carbon	400-9,000ppm	300mW	Precalibrated module
TGS2442	monoxide	30 - 1,000ppm	14mW	Compact size
TGS2602	General air contaminants	1 - 30ppm	280mW	High sensitivity to VOCs and odorous gases For leak detection from refrigerators and air conditioners Ceramic base resistant to severe environments
TGS832	Halocarbon gas	100 - 3,000ppm	835mW	Precalibrated module, Maintenance free, For gas leak detection in fuel cell systems
FCM6812	Hydrogen Methane LP gas	0 - 35%LEL	1.0 W	Ceramic base resistant to severe environments
TGS825	Hydrogen sulfide	5 - 100ppm	660mW	Catalytic type, Wide detection range, Linear output, For residential gas alarms
TGS6810	LP gas, Methane	0 - 100%LEL	525mW	High selectivity to methane gas
TGS2611-E00	Methane	500 - 10,000ppm	280mW	Stable relative sensitivity between CH <sub>4</sub> & LP gas, Good durability, For residential gas alarms
TGS2612	Methane, LP gas	500 - 10,000ppm 500 - 12,500ppm	280mW	
TGS3870	Methane & CO	50 - 1,000ppm	38mW	Dual gas detection with one sensor
SK-25	Oxygen	0 - 30%	No power required	Galvanic cell, Good linearity
TGS2180	Water vapor	1 - 150g/m <sup>3</sup>	830mW	High selectivity to water vapor



CO<sub>2</sub>:

Figaro's CDM4161-L00 **solid electrolyte CO<sub>2</sub> sensor** [5VDC, 0.3W.  
-10°C to 60°C, 5 to 95% RH [avoid condensation]

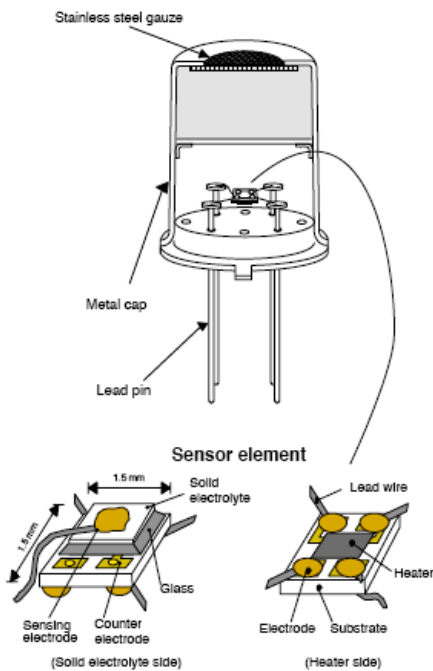
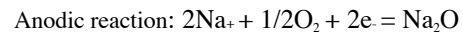
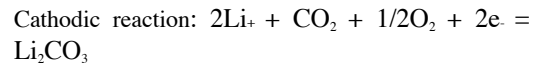
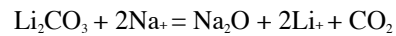


Fig. 1 - Sensor structure

When the sensor is exposed to CO<sub>2</sub> gas, the following electrochemical reaction occurs:



Overall chemical reaction:



As a result of the electrochemical reaction, electro-motive force (EMF) would be generated according to Nernst's equation:

$$\text{EMF} = E_c - (R \times T) / (2F) \ln (P(\text{CO}_2))$$

where

P(CO<sub>2</sub>) : Partial pressure of CO<sub>2</sub>,

E<sub>c</sub> : Constant value R : Gas constant

T : Temperature (K) F : Faraday constant

By monitoring the electromotive force (EMF) generated between the two electrodes, it is possible to measure CO<sub>2</sub>.



*Gas Sniper-01 Model for EPA Method 21*

utilizes hydrophobic filters to prevent moisture contamination. The Gas Sniper will continuously operate for up to 30 hours on alkaline batteries or 18 hours on Ni-Cad batteries. A maximum of 30 seconds is needed for instrument warm up.

#### **Principle of Operation**

**Depending on the specific gas being monitored, the Gas Sniper utilizes catalytic combustion, electrochemical cell, galvanic cell and infrared sensor technologies to accurately detect gases** within several full-scale ranges.

An integral, extremely **low power suction pump provides a continuous, steady sample flow** to provide accurate and repeatable measurements. Sample flow to the gas sensor is regulated and consistently monitored.

**Industrial Scientific Corp.** [ <http://www.indsci.com/default.aspx> ] has announced the MX6 iBrid™ Multi-Gas Monitor, an improved, 6-gas version of the existing CSA-CP, [compound specific analyzer-combustion products] that is expected to be available in mid-2011. See [http://www.indsci.com/news\\_releases.aspx?id=2405&terms=CSA](http://www.indsci.com/news_releases.aspx?id=2405&terms=CSA)

“The MX6 is designed to detect from one to six gases including oxygen, combustible gases and up to four toxic gases. With 25 field-replaceable “smart” sensor options, an integrated sampling pump, and interchangeable lithium-ion and alkaline battery packs, the MX6 can be set up in millions of different detection configurations. Such configuration flexibility allows it to measure potential hazards in any industry. The addition of a photo-ionization detector (PID) allows for the detection of the potentially “unknown” toxic hazards or volatile organic compounds that may exist in some applications.”

NOTE: this instrument uses transducing/detecting components that exhibit similar non-specific responses as do all such solid-state components [the “CO” sensor responds to acetylene, unsaturated hydrocarbons, but may have some compensation against H<sub>2</sub>; “HCN” sensor has negative response to NO<sub>x</sub>, etc.]. photo follows:



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